

TITLE OF THE INVENTION

METHOD FOR ESTIMATING ORIGIN TIME, HYPOCENTRAL DISTANCE, AND
SCALE BASED ON ELECTRIC FIELD OBSERVATION, AND
APPARATUS FOR PREDICTION

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BACKGROUND OF THE INVENTION

The present invention relates to a method for estimating the origin time, the hypocentral distance, and the scale of an earthquake from time-series data of measured 10 values of the electric field intensity which is observed accompanying the seismic ground motion, and to an apparatus for the prediction.

In the prior art, the origin time, the hypocentral distance, and the scale of an earthquake are calculated based 15 on the measurements of only P wave, or both P wave and S wave. It is necessary for calculation of these values to measure P wave of the same earthquake at four or more observation sites, when P wave only is used. Even when both P wave and S wave are used, it is necessary to measure P wave and S wave 20 of the same earthquake at three or more observation sites.

For example, in case the hypocentral distances of the four p wave observation sites are 100 km or shorter, the calculation of the origin time (time of earthquake occurrence), the hypocentral distances (distance from the 25 hypocenter to the observation sites), and the scale (magnitude M) requires at least 15 seconds, which is a time P wave requires to arrive at the observation sites. However, as a typical observation uses both P wave and S wave, the

calculation requires at least 25 seconds, which is a time
S wave requires to arrive at the observation sites in case
the hypocentral distances of the three observation sites are
100 km or shorter. No matter which method is used, the
5 hypocentral distance and the scale can not be known until
seismic waves arrive at three or four observation sites, that
is, for 15 or 25 seconds after the occurrence of the earthquake
in the above described cases.

SUMMARY OF THE INVENTION

10 It is an object of the present invention to resolve
the aforementioned problem by providing a simple method and
an apparatus which enable to detect the origin time almost
simultaneously with the occurrence of the earthquake, while
quickly estimating the hypocentral distance and the scale
15 before the arrival of seismic waves.

For this end, the method of the present invention is
a method for estimating the origin time, the hypocentral
distance, and the scale from time-series data of measured
values (measured data) of the electric field intensity which
20 is observed accompanying a seismic ground motion, and is
characterized by comprising collecting and storing the
measured data of the electric field intensity, detecting the
origin time from the starting time of electric field increase,
and estimating the hypocentral distance and the scale from
25 the elapsed time from the origin time and the measured data.

The apparatus of the present invention is an apparatus
for estimating the origin time, the hypocentral distance,
and the scale from time-series measured data of the electric

field intensity which is observed accompanying a seismic ground motion, and is characterized by comprising a measuring means for measuring the electric field intensity, a data storing means for collecting and storing measured data from 5 said measuring means, and a data analyzing means for analyzing data stored in said storing means to detect the origin time from the starting time of electric field increase and to predict the hypocentral distance and the scale from the elapsed time from the origin time and the measured data.

10 It is further characterized in that the hypocentral distance D and the scale M are predicted from a relation between the elapsed time t from said origin time and an electric field intensity E(t) at the time t, by using two or more measured data based on the following formula:

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$$E(t) = a10^M / \{D - r(t)\}^b$$

wherein a, b: constants which depend on geology and electric field observing system; and

$r(t)$: distance between hypocenter and P wave front at time $t = t \times$ Speed of P wave,

20 and that the origin time, the hypocentral distance, and the scale are predicted by using a seismograph for measuring seismic waves together with the above.

Still other objects and advantages of the invention will in part be obvious and will in part be apparent from 25 the specification.

The invention accordingly comprise the features of construction, combinations of elements, and arrangement of parts which will be exemplified in the construction

hereinafter set forth, and the scope of the invention will be indicated in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration for explaining an embodiment 5 of the method according to the present invention for estimating the origin time, the hypocentral distance, and the scale based on the electric field observation;

FIG. 2 is a diagram showing a constitution example of 10 an apparatus for estimating the origin time, the hypocentral distance, and the scale according to the present invention; and

FIGS. 3(A), 3(B) are graphs showing an observation example of the electric field generated simultaneously with an earthquake, and P wave of the same earthquake.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of the present invention will be described hereinafter with reference to the drawings. FIG. 1 is an illustration for explaining an embodiment of the 20 method according to the present invention for estimating the origin time, the hypocentral distance, and the scale based on the electric field observation. In FIG. 1, numeral 1 designates a hypocenter, 2 designates a seismic wave propagating from the hypocenter, 3 designates a wave front 25 which represents P wave front and a charge front at once. Numeral 4 designates an induction field induced by the charge front, and 5 designates an electromagnetic field sensor for measuring the electric field.

As shown in FIG. 1, a seismic wave 2 arises at hypocenter 1 simultaneously with the occurrence of an earthquake and propagates from the hypocenter. As P wave is the fastest to propagate, the wave front of seismic wave comprises the p wave front. P wave is a longitudinal wave, and its wave front comprises a charge front 3. The charge front 3 induces an electric field resulting in the propagation of an induction field 4.

As will be described later in an observation example, 10 the induction field 4 arises simultaneously with the occurrence of an earthquake, increases its intensity synchronously with the propagation of the P wave, and reaches the maximum at the arrival of P wave. The electric field decreases from the arrival time of P wave to the arrival of 15 S wave, no electric field synchronized with S wave propagation being observed. No electric field pulse due to P wave is observed, while electric field pulse is generated at the arrival time of S wave.

The intensity of the induction field 4 can be measured 20 by an electromagnetic sensor 5 and the measured data can be analyzed to detect origin time from the starting time of the electric field increase, and to predict the hypocentral distance and the scale (magnitude M) from the elapsed time from the origin time and the measured data from the 25 electromagnetic sensor 5.

Assuming that a charge is generated on the wave front of P wave, the wave form of the induction field 4 synchronized with the P wave propagation can be quantitatively explained

with the induction field. Observation shows that its amplitude is nearly inversely proportional to square of the distance from P wave front to the electric field observation site. The magnitude M is often defined as common logarithm
5 of the maximum velocity amplitude of a seismic ground motion. In addition, since flow potential and piezoelectric charge are proportional to the maximum velocity amplitude, if the charge is due to flow potential or piezoelectric charge, the field should be proportional to the M-th power of 10.
10 Therefore, the magnitude M can be obtained from the following formula:

$$E(t) = a10^M / \{D - r(t)\}^b$$

where E(t): field intensity at elapsed time t from origin time;

15 a, b: constants which depend on geology and electric field observing system;

D: hypocentral distance; and

r(t): distance between hypocenter and P wave front at time $t = t \times$ Speed of P wave.

20 The above formula shows that the magnitude M and the hypocentral distance D can be predicted even before the arrival of P wave, from the relation between elapsed time t from the origin time (starting time of electric field increase) and electric field amplitude (electric field intensity) E. That is, the above formula having the magnitude M and the hypocentral distance D as unknown values can be solved when two or more measured data of field intensity E(t) at time t are available, thus obtaining the magnitude M and
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the hypocentral distance D. Supposing a sampling cycle of 0.1 second, 10 measured data can be obtained in 5 seconds after the occurrence of an earthquake. This allows a seismic ground motion to be predicted in several seconds, i.e. prior 5 to the arrival of P wave, cutting the time conventionally required for the prediction by 10 seconds or more in the previously described case. Therefore, the prediction prior to the arrival of seismic waves becomes possible in most of the local regions.

Now, the constitution of the observation apparatus and its operation will be described. FIG. 2 is a diagram showing a constitution example of the apparatus for estimating the origin time, the hypocentral distance, and the scale according to the present invention. Numeral 21 designates 10 an electrode, 22 designates a receiver, 23 designates a seismograph, 24 designates a data collecting part, 25 designates a data storing part; 26 designates a data analyzing part, and 27 designates a pen recorder.

In FIG. 2, the electrode 21 outputs a potential difference between electrodes. The receiver 22 decreases the output voltage in the unnecessary bands contained in the output voltage received from the electrode 21, while amplifying the output voltage in the necessary bands to a necessary voltage (typically lower than 10 V). The 20 seismograph 23 converts the amplitudes of acceleration and the like due to seismic wave into voltage to output. The data collecting part 24 collects measured data from the receiver 22 and the seismograph 23 at a predetermined sampling cycle 25

(0.1 second or less). The data storing part 25 stores the collected data in memory means after determining whether the data are useful or not.

The data analyzing part 26 analyzes collected and
5 stored data in the memory means of the data storing part 25,
detecting the electric field occurring simultaneously with
the earthquake, estimating the origin time from the starting
time of the electric field increase, and estimating the
hypocentral distance and the scale from the elapsed time from
10 the origin time and the measured data, and outputs the results.

The pen recorder 27 monitors the measurements of the
electrode 21, the receiver 22, and the seismograph 23. When
using the measured data from the seismograph 23, P wave is
detected and the hypocentral distance and the scale are
15 predicted from the measured data of P wave and the measured
data of the electric field intensity.

Now, the processing of the measured data will be
specifically described with reference to an observation
example. FIGS. 3(A), 3(B) are graphs showing an observation
20 example of the electric field generated simultaneously with
an earthquake, and P wave of the same earthquake. The example
relates to an earthquake which actually occurred on June 14,
2002, as is shown in the following table. The curves are shown
in relation with time in order to predict the origin time,
25 the hypocentral distance, and the scale of this earthquake.
Numeral 31 designates the electric field which arises
simultaneously with the earthquake, 32 designates the
acceleration in south-north direction, 33 designates the

acceleration in east-west direction, 34 designates
acceleration in perpendicular direction, 35 designates
origin time, 36 indicates the arrival time of P wave, 37
designates a singular point in the electric field intensity,
5 and 38 designates the starting time of the electric field
pulse increase due to the arrival of S wave.

The earthquake in the southwest region of
Ibaragi prefecture on June 14, 2002
Hypocenter: $36^{\circ}23'7''$ N, $139^{\circ}49'7''$ E, depth: 57 km
10 Magnitude: 4.9

Observed electric field and time of earthquake
Starting time of field increase 11:42 49.0 sec.
Origin time (calculated value) 11:42 49.99 sec.
Field maximum time 11:43 04.4 sec.
15 (Maximum: 0.45 mV)
Arrival time of P wave 11:43 03.65 sec.

(Time difference of 0.75 sec. between field maximum and the
arrival of P wave corresponds to length of hypocentral
region)

20 Starting time of field impulse increase
11.43 15.0 sec.
(Maximum: 12 mV)

Arrival time of S wave (calculated value) 11.43 14.0 sec.

Observation site: 402 Ootaoshiage, Hasaki-cho, Ibaragi
25 Prefecture $35^{\circ}49'7''$ N, $140^{\circ}43'9''$ E
Epicentral distance: 78.4 km Hypocentral distance: 98 km
Observation frequency: 0 - 0.7 Hz, 0.01 - 0.7 Hz
Electrode: A steel pipe of 805 m inserted in a perpendicular

drilling and copper wires buried around it.

Recorder: San-ei 8D20A available, Recording speed: 2 mm/sec.

Recording sensitivity: 1 mV/cm

Toa-Pegasus INR-6041, Recording speed: 30 mm/H

5 Recording sensitivity: 10 mV/2.5 cm

According to the above described observation example,

the electric field 31 generated simultaneously with the earthquake continued to exist until the seismic waves became unobservable. All of the acceleration records including

10 acceleration in south-north direction 32, the acceleration in east-west direction 33, and acceleration in perpendicular direction 34 are recorded by a strong motion seismograph installed in Choshi located at 14 km southeast of the electric field observation site (Hasaki). The origin time 35

15 (calculated value) coincides with the starting time of electric field increase, that is 11:42 49.0 sec., within the range of the calculation error. The arrival time of P wave 36 is an observation value of high sensitivity seismograph installed at the electric field observation site (Hasaki).

20 The singular point 37 in the electric field intensity curve is a point at which the field curve turns from increase to decrease. The starting time of field pulse increase 38 coincides with the arrival time of S wave in FIG. 2. However,

this is an observation data obtained in Choshi which is at 25 a distance of 11 km from the electric field observation site (Hasaki), and the actual arrival time of S wave at Hasaki is 1 second earlier than the starting time of field pulse increase 38. This difference of 1 second is due to a phase

delay of induced voltage induced by the transverse wave of S wave.

In the case of the above-described observation example, the hypocentral distance 98 km is obtained from a product 5 of time difference 13.7 seconds between the arrival time of P wave 36 and the origin time 35, and the P wave propagation speed 7.2 km/second. The scale can be obtained according to the prior art from the relation between the hypocentral distance and the amplitude of seismic wave. However, it can 10 be obtained also from a difference between the arrival time of P wave 36 and the singular point of electric field 37, in the following manner. In the case of the present observation example, this difference is 0.8 second, which is multiplied by the propagation speed of P wave to give the 15 length of the hypocentral region 5 km, which corresponds to a hypocentral region length of an earthquake with magnitude 5 (typical magnitude error is 0.5).

As the amplitude of the electric field (electric field intensity) increases with the magnitude, and is inversely 20 proportional to square of the distance between the wave front of P wave and the electric field observation site, the magnitude and the hypocentral distance can be predicted prior to the arrival of P wave, from the relation between the elapsed time from the origin time 35 (starting time of field increase) 25 and the electric field amplitude. Thus, the above described formula having magnitude and hypocentral distance as unknown values, can be solved when two or more measured values of the electric field amplitude $E(t)$ at time t as elapsed time

from the origin time 35 are available, so as to uniquely obtain the magnitude and the hypocentral distance. Accordingly, the magnitude and the hypocentral distance can be predicted in several seconds after the occurrence of the earthquake, i.e. 5 prior to the arrival of seismic waves.

The measurement of the electric field intensity by the electromagnetic sensor 5 in this embodiment is preferably performed at a place where the level of both natural noise and artificial noise are sufficiently low. For instance, as 10 the electric field accompanying the earthquake is in the order of 0.4 μ V/m, it is preferable that the natural noise and the artificial noise are in the order of 0.1 μ V/m or lower in 0.01-30 Hz band which is regarded to be an optimum observation band.

15 In addition, the present invention is not limited to above-described embodiment, and various modifications may be made. For example, though the origin time, the hypocentral distance, and the scale are predicted at a single observation site in the embodiment, the conventional technique using P 20 wave and S wave may be applied in order to obtain the hypocenter location from the hypocentral distance.

As apparent from the above discussion, according to the present invention, the method for estimating the origin time, the hypocentral distance, and the scale from the 25 time-series measured data of the electric field intensity which is observed accompanying a seismic ground motion comprise collecting and storing measured data of the electric field intensity, detecting the origin time from the starting

time of electric field increase, and estimating the hypocentral distance and the scale from the elapsed time from the origin time and the measured data. In addition, the apparatus for estimating the origin time, the hypocentral 5 distance, and the scale from time-series measured data of the electric field intensity which is observed accompanying a seismic ground motion comprises a measuring means for measuring the electric field intensity, a data storing means for collecting and storing measured data from the measuring 10 means, and a data analyzing means for analyzing the measured data stored in the storing means, to detect the origin time from the starting time of electric field increase, and to predict the hypocentral distance and the magnitude from the elapsed time from said origin time and the measured data. 15 Hence, the origin time, the hypocentral distance, and the scale can be quickly predicted prior to the arrival of seismic waves by measuring and analyzing the electric field intensity.

Accordingly, the present invention can be utilized for 20 emergency stopping of installations such as nuclear reactor, high-speed railway, high-speed motor road, and airport, prior to the arrival of the seismic waves.